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JOINT COMMITTEE ON ATOMIC ENERGY

CURRENT STATEMENT OF THE ATOMIC ENERGY COMMISSION

ON THE

FIVE-YEAR REACTOR DEVELOPMENT PROGRAM

TO THE

SUBCOMMITTEE ON RESEARCH AND DEVELOPMENT

MAY 4, 1955

Printed for the use of the Joint Committee on Atomic Energy

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FOREWORD

The attached report from the Atomic Energy Commission is printed for the information of the members of the Research and Development Subcommittee and others whom it concerns or may affect. The report has not been reviewed by the subcommittee and publication at this time does not connote approval of the policies or programs contained herein, either express or implied.

The subcommittee intends to hold a hearing on the report in late May or early June for the purpose of examining the import of the policies and programs set forth. Comments and observations, either in writing or in the form of prepared statements for presentation to the subcommittee, by any interested persons or organizations are invited. Such comments and observations should be submitted to the subcommittee as soon as possible.

LETTERS OF REQUEST AND ACKNOWLEDGMENT

MARCH 2, 1955.

Hon. LEWIS L. STRAUSS,
Chairman, Atomic Energy Commission,
Washington, D. C.

DEAR MR. STRAUSS: On July 31, 1953, the Joint Committee on Atomic Energy requested by letter that the Atomic Energy Commission prepare an outline of the objectives it seeks to achieve in the field of reactor development over the next 5 years and of its program for accomplishment of these objectives. The result of this request was the 5-year power reactor development program which was submitted to the Research and Development Subcommittee for review on February 5, 1954.

After the subcommittee completed its review of this program, a report was issued which took cognizance of the fact that during the review "the Commission assured the committee that, whenever possible, the entire 5-year program will be speeded up as a result of any new scientific or engineering advances." From time to time during subsequent testimony before the committee and in correspondence, the Commission has noted changes which it is undertaking in the scope and rate of prosecution of this program.

The original report has proved very useful to the full committee. In addition, a principal benefit has been that it provided a complete outline of the Commission's activities in this field in a suitably concise form as a reference to assist interested industrial groups in their own planning. It is now apparent that sufficient changes have occurred to warrant an updating of this program report. The subcommittee therefore requests that the Commission present a current statement of its power reactor development program to the subcommittee within the next 60 days. This current statement should include both changes in scope and rate of prosecution of projects in the original program as well as information on additions to or deletions from the program. It should be in suitable form for release as part of an unclassified report by the subcommittee. A classified version for the use of the subcommittee and others interested in this matter may also be desirable.

The subcommittee is currently formulating plans for inspection visits to the various laboratories and installations of the Commission involved in work on the 5-year program. It is our intention to complete as many of these visits as possible before the Commission presents its statement on the program.

The committee staff is available to work out any details involved in the scheduling of both the presentation of testimony and of the inspection visits.

Sincerely yours,

MELVIN PRICE,
Chairman, Subcommittee on Research and Development.

UNITED STATES ATOMIC ENERGY COMMISSION,
Washington 25, D. C., March 4, 1955.

Hon. MELVIN PRICE,
Chairman, Subcommittee on Research and Development,
Joint Committee on Atomic Energy,
Congress of the United States.

DEAR MR. PRICE: This is to acknowledge your letter of March 2, 1955, requesting a current statement of the Commission's power reactor development program be submitted to the subcommittee within the next 60 days.

We will be happy to prepare the statement requested by you and make the necessary arrangements for the visits of the Subcommitte on Research and Development to our installations.

Sincerely yours,

J. L. KELEHAN,
Assistant General Manager for Administration
(For the General Manager).

LETTER OF TRANSMITTAL

UNITED STATES ATOMIC ENERGY COMMISSION,
Washington 25, D. C., April 29, 1955.

Hon. MELVIN PRICE,
Chairman, Subcommittee on Research and Development,
Joint Committee on Atomic Energy,
Congress of the United States.

DEAR MR. PRICE: I am forwarding herewith an unclassified current statement of the Atomic Energy Commission's power reactor development program as requested in your letter of March 2, 1955.

Much of the information contained in this statement was, of course, supplied to the Joint Committee on Atomic Energy during the hearings on the development, growth, and state of the atomic energy industry on January 31, February 1, 3, and 4, 1955.

This statement is limited to material believed to provide a suitable sequel to the report issued by the Subcommittee on Research and Development in March 1954 summarizing our report of February 5, 1954, "Program Proposed for Developing Nuclear Power Plant Technology." It is primarily a statement of the current status and proposed plans on civilian power reactors.

The Commission and its staff would be pleased to discuss any phase of this statement or to supply additional information as needed.

Sincerely yours,

W. F. LIBBY, *Acting Chairman.*

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CURRENT STATEMENT OF THE ATOMIC ENERGY COMMISSION ON THE FIVE-YEAR REACTOR DEVELOPMENT PROGRAM TO THE SUBCOMMITTEE ON RESEARCH AND DEVELOPMENT

Power Reactor Development Program

I. INTRODUCTION

The Atomic Energy Commission's program for the development of nuclear powerplant technology for civilian application or peacetime uses was formalized in February 1954. This program was established and has been proceeding on the basis that it is the responsibility and objective of the Commission as an agency of the Government to develop power reactor technology, both directly and indirectly, to the point where one or more power reactor systems are technically and economically feasible, and beyond that, to develop technology for even more advanced types of power reactors. Emphasis in the program has been placed on the development of advanced reactor technology through projects of building experimental reactors. These reactors were chosen to represent five power reactor concepts believed to be potentially capable of producing economically competitive nuclear power and sufficiently well advanced in technology at the time to make reactor construction technically feasible. These concepts are (*a*) pressurized water reactors, (*b*) boiling water reactors, (*c*) sodium graphite reactors, (*d*) fast breeder reactors, and (*e*) homogeneous reactors. These experimental reactors are not expected to be economical power producers but are to provide progress in that direction for future plants utilizing the technology resulting from their development, design, assembly, and operation.

The program formalized over a year ago was planned as a minimum program financed primarily by the Government, for the purpose of developing power reactor technology. It was so planned with the assumption that, as the goal of economically competitive nuclear power is approached, industry would accept an increasing share of the responsibility for this development and would invest its money in subsequent power demonstration reactor plants. Recent events are believed to justify this assumption. These events include the request from the Consolidated Edison Co. for a license to build a large scale nuclear powerplant and proposals from four other organizations (Nuclear Power Group,[1] Detroit Edison Co. and Associates,[2] Consumers Public Power District of Nebraska, and Yankee Atomic Electric

[1] Composed of American Gas & Electric Service Corp., New York; Bechtel Corp., San Francisco, Calif.; Commonwealth Edison Co., Chicago, Ill.; Pacific Gas & Electric Co., San Francisco, Calif.; and Union Electric Co., St. Louis, Mo.

[2] Central Hudson Gas & Electric Corp., Poughkeepsie, N. Y.; Cincinnati Gas & Electric Corp., Cincinnati, Ohio; Consumers Power Co., West Jackson, Mich.; Delaware Power & Light Co., Wilmington, Del.; Detroit Edison Co., Detroit, Mich.; Long Island Lighting Co., Mineola, N. Y.; Philadelphia Electric Co., Philadelphia, Pa.; Rochester Gas & Electric Corp., Rochester, N. Y.; Toledo Edison Co., Toledo, Ohio.

Co.[3]) to build large scale nuclear powerplants under the Commission's power demonstration reactor program. These plans and proposals are still being studied as this statement is written, but they certainly indicate that American industry is ready to cooperate in the development of nuclear powerplants. They indicate further that success is being achieved in the Commission's program of developing technology and that industry has confidence in continuing progress. In each case, those making proposals have emphasized that they are depending, as a minimum, upon the continuance of the AEC's program for much of the basic data required for the success of their projects.

It is, of course, neither possible nor desirable to plan and execute a development program in a completely inflexible manner. The entire power reactor program has been under continuous review to take advantage of new technical developments or other situations permitting acceleration of the various activities or improvements in design and expected performance of the experimental reactors. In addition, general research and development effort in exploration of other types of reactors has continued and results used for appraisal of new reactor powerplant concepts which may justify more intensive attention as specific reactor projects.

A major problem in the rapid rate of progress being attempted arises from the critical shortage of well-trained, experienced scientific and engineering manpower. This problem has become particularly acute as industrial interest in the nuclear power field has risen sharply and increased competition for the limited numbers of experienced people. Large relocations of personnel are, of course, natural to the desired establishment of a nuclear power industry. However, there is a certain danger that such relocations may take place so rapidly and in such mass as to have an undesirable influence on the basic technological program believed necessary to provide a sound foundation for that industry. This problem is receiving serious attention, including consideration of ways and means for expanding the training program.

It is believed that the purposes of this report will be served best by including (*a*) further discussion of the philosophy of the Commission's civilian power reactor program; (*b*) current and proposed plans for the experimental reactor projects included in the original program; (*c*) a review of new developments or ideas suggesting a somewhat expanded scope for the program; and (*d*) a brief note on revised cost estimates.

II. PHILOSOPHY OF THE COMMISSION'S CIVILIAN REACTOR PROGRAM

The early development of economically competitive nuclear power by the United States is an important national objective. It cannot be guaranteed that extensive exploitation of the power reactor concepts now available will result in economically competitive nuclear power but there are good reasons for believing that it is an attainable goal. The underlying philosophy with which this goal is sought undoubtedly will affect the time schedule, the cost, and, in fact, the

[3] Members of which are New England Power Co., Boston, Mass.; Connecticut Light & Power Co., Hartford, Conn.; Boston Edison Co., Boston, Mass.; Central Maine Power Co., Augusta, Maine; Hartford Electric Light Co., Hartford, Conn.; Connecticut Power Co., Hartford, Conn.; Western Massachusetts Electric Co., Greenfield, Mass.; Public Service Company of New Hampshire, Manchester, N. H.; Montaup Electric Co., Fall River, Mass.; New Bedford Gas & Edison Light Co., New Bedford, Mass.; Cambridge Electric Light Co., Cambridge, Mass.; Central Vermont Public Service Corp., Rutland, Vt.

ultimate success of the program. It is important to recognize that this goal involves both technolgical and economic factors. Without the economic factor the goal could be considered as having been achieved since the technical feasibility of nuclear power has been demonstrated in several different reactors utilizing all of the major materials and design concepts now being developed on a project basis. Power has been produced with pressurized water, and liquid metal systems; with heterogeneous and homogeneous reactors; and with thermal and fast neutron energy reactors. These accomplishments provide a solid background of power reactor technology. The need now is to extend that technology into regions particularly influential on ultimate power costs. The present program does not strive for large blocks of nuclear power immediately but for the technology which will make nuclear power less expensive.

Achieving economically competitive nuclear power in an accelerated time schedule is believed to be desirable, if not essential, for both domestic and international reasons. It may be possible to reduce the total cost of the development by acceleration of the program and, if economic gains are to be realized via nuclear power, the total gain will be greater if the goal is achieved at an earlier date. On the international side, nuclear power is expected to have important economic advantages in many foreign locations and it is important that the United States be in a leading position for assisting other countries in realizing these advantages.

With these thoughts in mind, the Commission has adopted the following basic philosophy for further planning of the civilian power reactor program:

(*a*) It is in the national interest to expand the present program in a manner which will accelerate the achievement of competitive nuclear power and improve the effectiveness of American assistance to other countries in nuclear power field.

(*b*) Developing economically competitive nuclear power for civilian use will be aided by maximum practical utilization of the financial incentive common to business ventures in order to stimulate ingenuity and imagination and the assumption of calculated technical and economic risks.

(*c*) The Commission's role should be to develop advanced technology at Government expense and to stimulate outside groups to undertake developmental or demonstration power projects primarily with non-Commission financing.

(*d*) Positive steps of assistance to other countries should be included as part of the program.

The philosophy stated above is not different in any major way from the philosophy used as a basis for formulation of the program proposed in February 1954, though this may constitute a more explicit statement than previously given. It reflects, primarily, a reappraisal of the promise, the feasibility, and the importance of rapid development of nuclear powerplant technology.

It is the Commission's intent to stimulate outside groups to undertake developmental or demonstration power reactor projects with financing of the type normal to the particular group's activities. This policy is implemented by the Commission's power demonstration reactor program. This program was announced on January 10, 1955,

along with announcement of availability of a schedule of prices for materials and services controlled by the Commission.

Reactor projects resulting from the power demonstration reactor program are to have primary technical and financial responsibility rested in the industrial group making the proposal. The Commission's financial contribution, if any, will be fixed in amount as the project is approved and overruns in cost must be borne by the industrial organization. In its invitation to industry to develop, construct, and operate these demonstration power reactor plants, the Commission stated that it would consider offering certain assistance including the following:

1. Waiving of charges for loan of source and special nuclear material for fuel for a period up to 7 years.
2. Purchase by the Government of special nuclear materials produced.
3. Performing research and development in Commission facilities.
4. Support of research and development in non-Commission facilities.

It must be recognized that the form of assistance which the Government offers to stimulate construction of power demonstration reactors can have a significant influence on the types of reactors which will be built as a result of the program. Since economic civilian power is the primary objective of the program, the assistance must be of such form as to encourage development of reactor plants with characteristics important to eventual production of minimum cost nuclear power.

There are certain basic conflicts, for example, between reactor specifications which may be desirable for high materials production and those which are desirable for low cost power production. One simple illustration of this conflict may be apparent from the fact that once new fissionable material is formed in a reactor it also can be destroyed and the net rate of production of the new material decreases with fuel exposure. Thus, if large revenues are expected from sale of material, relatively short fuel cycles are satisfactory. On the other hand, minimum cost power in a "power only" economy requires long fuel cycles in order that costs of fabrication, processing, and handling the fuel will not be large in terms of mills per kilowatt-hour of power produced by the plant. There are other conflicts of this type and the specific reactor design will always be optimized for maximum revenue whether the source be power or material. The pricing policy and power demonstration power reactor program approved by the Commission provide a balance of probable sources of revenue from such projects to stimulate projects helpful to early realization of economically competitive civilian nuclear power.

The invitation to industry to submit proposals for construction of power demonstration reactor plants is an important part of the overall civilian power reactor program. The program approved last year, which has become popularly known as the 5-year program is primarily for the purpose of providing technology. Except for the PWR, the reactor projects are on a small scale and of relatively low total cost. On the other hand, power demonstration reactor plants will be of a generally larger size primarily to furnish data on operation and components engineering that can be obtained only by large-scale units.

Furthermore, the power demonstration reactor program may include concepts other than or variations upon the designs represented by the 5-year program. The deadline for submission of proposals under the first round of the power demonstration reactor program was April 1, 1955. Four proposals and one license application were received and are being evaluated as previously indicated. Consideration is being given to subsequent rounds of this program.

III. STATUS OF CIVILIAN POWER REACTOR PROJECTS

Five reactor concepts were selected in February 1954 as being potentially capable of producing economically competitive nuclear power and sufficiently well advanced in technology to make construction of experimental reactors for each concept technically feasible. The concepts selected and the reactor projects which are proceeding to explore each concept continue to be considered a reasonable program. Some development problems have been solved, some remain to be solved, and some new ones not previously considered have become known. All of the concepts selected continue to show promise of ultimate production of civilian power at competitive costs in future nuclear powerplants. Some modifications in the program have been made, others are proposed or under active consideration. The current status and proposed future of the reactor projects in the original program are reviewed briefly in the following paragraphs. The Report of the Subcommittee on Research and Development on the Five-Year Power Reactor Development Program Proposed by the Atomic Energy Commission, dated March 1954, has been taken as the point of reference in the preparation of this statement. Design information on the individual projects is included only as necessary to show changes in the program.

Pressurized water reactor

The pressurized water reactor (PWR) will be the first large scale nuclear powerplant operated in this country. It is to produce at least 60,000 kilowatts of electricity net and is the only large scale reactor in the original development program. It is considered important to have one such large scale plant in the program to provide reliable cost data relative to construction, operation, and maintenance of large central station nuclear powerplants.

In response to invitations by the Commission to utility and industrial groups to participate in and make contributions to this project, the proposal submitted by the Duquesne Light Co. of Pittsburgh, Pa., was the most favorable to the Government, and the Atomic Energy Commission has entered into a contract with this company. Under the contract Duquesne will furnish a site for the entire project, will build and operate a new turbogenerator plant, will operate the reactor portion of the plant, will assume up to $5,000,000 of the costs connected with development and construction of the reactor portion of the plant, and will purchase at specified rates, steam generated by the reactor.

The Westinghouse Electric Corp. is the Commission's principal contractor for the design, development, and construction of the reactor portion of the plant. The Stone & Webster Engineering Corp., under subcontract to Westinghouse, is performing architect-engineering services for this part of the plant.

The Duquesne Light Co. has engaged an engineer-constructor for the turbogenerator portion of the plant.

An extensive development effort is being pursued to produce fuel element and reactor structural materials which can successfully resist the extreme operating conditions induced by radiation, heat, and corrosion. Development contracts for new types of pumps and valves have been given to major industrial organizations.

The plant will be located on the Ohio River at Shippingport, Pa., about 25 miles from Pittsburgh, and in reasonably close proximity to populated areas. Initial ground breaking took place September 6, 1954, excavation is now proceeding and large-scale construction will be started by midsummer of 1955. Initial power generation from the plant is expected in mid-1957.

This project is being expedited along lines originally planned. The associated development work is yielding much scientific and engineering technology vital to future designs of all water moderated and cooled power reactors and it is planned that work will continue in this manner.

It is significant to note that two of the large-scale reactors proposed for construction by industry, Consolidated Edison Co. and the Yankee Atomic Electric Co., are water moderated and cooled designs of the general type of the PWR. These reactors are designed to operate at lower system pressure and include other design differences. The total capacity of these two plants would be about 340,000 kilowatts.

Boiling water reactors

The concept of boiling water reactors is being investigated in a project under the direction of Argonne National Laboratory. This concept basically is a variation of the pressurized water reactor concept, the distinction being that in the boiling designs coolant system pressure is lowered and steam generation allowed to take place in the core. Three experimental reactors are involved in the overall project. The first, a boiling reactor experiment known as Borax I, was operated at the NRTS in 1953 and provided a basis for confidence in proceeding with development of boiling reactors. Operation of this reactor was resumed in the summer of 1954 following some modification and reconditioning of the facility. A successful series of tests was conducted on the operation and reliability of various reactor safety fuses. As a continuation to the series of experiments conducted during 1953 in which runaway conditions were imposed upon the reactor, one final power excursion was performed on July 22, 1954. During this excursion the power rose to well over a million kilowatts in a tenth of a second and resulted in the destruction of the reactor core and some associated equipment. The conditions imposed in this final excursion were much more severe than would occur in any reasonably conceivable accident.

A second boiling reactor experiment (Borax II) was constructed during last summer on a site close to that of the original facility. The reactor became critical on October 19, 1954, and has been successfully operating since that date. The experiment, designed as a semipermanent facility to enable operation during the winter months, was built to demonstrate certain operational characteristics of a boiling water system. The Borax II reactor operates at higher pressure and power than did Borax I, but much less than required for central

station nuclear powerplants of this type. Experiments have been conducted to study both the steady state and transient behavior of the reactor and to define the limits of stable operation as a function of variables such as pressure, and specific power. The information being derived from these experiments will be of great value in the fabrication and initial operation of the experimental boiling water reactor, the third reactor of this project, which is now under design. In addition to a continuation of the present experimental program it is proposed to add a turbogenerator to Borax II. This would quickly provide information applicable to the EBWR particularly on power level control and would also provide data of value to the military in evaluating a small boiling water reactor as a possible design for future small scale power units.

The aim of the boiling reactor project is the construction and operation of the experimental boiling water reactor powerplant designed to produce 20 megawatts of heat and 5,000 kilowatts of electricity. This plant was conceived as a minimum capacity which will enable sound extrapolation to large size central station powerplants. It has been decided to construct the reactor at the Argonne National Laboratory near Chicago and to use ordinary water initially as both moderator and coolant.

An architect-engineer for the experimental boiling water reactor building was selected and a lump-sum contract awarded to Sargent & Lundy of Chicago, Ill. The first phase of this A–E work is completed. A lump-sum contract for the design, construction, and installation of the power equipment has been awarded to Allis-Chalmers Manufacturing Co. The specifications require the power system components to be leaktight, thus enabling evaluation of the possibility of using heavy water rather than ordinary water in boiling reactors. It is expected that this reactor eventually will be operated with heavy water as moderator and coolant. Heavy water is believed to offer some economic advantage in larger sized plants. In addition, heavy water facilitates the use of natural uranium as reactor fuel. Bids for the construction of the reactor building have been invited and construction at ANL is scheduled to begin in May 1955. This reactor plant should be generating power during the latter part of 1956.

The proposal of the Nuclear Power Group for construction of a large-scale plant (180,000 kilowatts) is based on a reactor design utilizing the boiling concept.

Sodium graphite reactor

Nuclear powerplants based on graphite moderation and sodium coolant continue to look promising for production of competitive power and fabrication of a small experimental reactor designed SRE (sodium reactor experiment) is proceeding on schedule.

The objective in constructing this reactor is to provide a firmer basis for estimating the performance and economies of this type plant on the basis of existing technology and perhaps more importantly to provide a flexible tool to develop the advanced technology necessary to attain economically competitive power.

Responsibility for the design, fabrication, and operation of this reactor was assigned to North American Aviation, Inc. The Commission has executed a contract with NAA which provides for a total

expenditure of $10 million during the period fiscal year 1954 through 1958. Approximately 40 percent of this sum is required for fabrication of the reactor and associated buildings and the remaining 60 percent will be used in research and development. This contract with North American is unique in that it represents one of the first joint industry-AEC financial ventures. North American Aviation, Inc., will provide $2.5 million of the funds required.

Detailed design work for the SRE is essentially complete, site preparation has been completed, and building construction is in process. In addition to the progress on the buildings a large number of tests are being conducted on sodium pumps, fuel-handling equipment, fuel rod cladding and assembly, zirconium welding and reactor physics experiments. The major components of the reactor and cooling system are out for competitive fixed price bid. Present schedules call for completion of fabrication by January 1956.

Original plans did not provide for any generation of steam or electricity with the sodium reactor experiment. However, consideration is now being given to a proposal whereby a utility company would provide, at its own expense, a heat exchanger and turbogenerator plant of about 7,500-kilowatt capacity to be attached to the SRE and would further compensate the Commission for power generated.

Research and development effort supporting this project has been restricted as a result of the nature of the contract with North American Aviation which places a ceiling on the allowable cost of the project. This arrangement has not provided the flexibility necessary in a development project of this type in order to assure adequate attention to technical problems. It is planned that this situation be alleviated somewhat to permit more nearly adequate exploration of the sodium cooled thermal reactor concept.

The proposal of the Consumers Public Power District of Nebraska to build a plant of 75,000-kilowatt capacity is based upon an extrapolation of the sodium reactor experiment.

Fast breeder reactors

An important objective of the Commission's reactor program is the development of reactors capable of producing more fissionable material than they consume. The goal of the present fast breeder reactor project, under the direction of Argonne National Laboratory, is the construction and operation of a sodium-cooled, 62.5-megawatt heat, 15,000 kilowatts electrical, experimental breeder reactor powerplant (EBR No. 2).

The first experimental breeder reactor (EBR No. 1), located at the NRTS in Idaho, has maintained a continuous operating schedule since its startup in 1951, and provides the stepping stone to the much larger EBR No. 2.

The development program for the experimental breeder reactor No. 2 is now well under way. The complex physics problems that arise in fast reactors are being solved on the UNIVAC electronic computer at New York University. Reactor physics measurements required for the program were made with a subcritical core assembly using the neutron source reactor at the Argonne National Laboratory. These exponential experiments are nearly completed and the data is presently being analyzed by the AVIDAC electronic computer at Argonne. The construction of a zero power fast critical assembly is nearing

completion at the National Reactor Testing Station. This facility, scheduled to begin operation this spring, will provide accurate data for the detail design of the core of EBR No. 2. To demonstrate the engineering feasibility of the EBR No. 2 design, a nonnuclear working model of the reactor portion of the plant has been designed and assembled. The model is approximately half scale and is located at Argonne.

Construction of EBR No. 2 is scheduled to start in 1956 and the reactor is scheduled to be in operation early in calendar year 1958.

A facility for the development, manufacture, and reprocessing of fuel elements containing plutonium is an essential requirement for the development of fast breeder reactor powerplants. The architect-engineering for such a facility, to be located at Argonne, has been completed and bids for construction solicited. The building is scheduled for completion this year. Increased attention is planned on alternate fuel systems for fast breeder reactors. Also, preliminary thought has been given to experimental determination of the safety characteristics of fast reactor designs.

The Commission-sponsored program on fast breeder power reactors is supplemented by significant industrially supported effort. Close liaison is maintained between these programs. This industrial effort has resulted in a proposal from the Detroit Edison Co. and associates previously listed to build a fast power breeder reactor designed to produce 100,000 kilowatts of electricity.

Homogeneous reactors

The homogeneous reactor concept has certain potential advantages, including low cost due to simplified design, economical chemical processing, and elimination of fuel element fabrication. It is the objective of the Commission's homogeneous reactor project to provide the technology necessary to realize these potential advantages. The homogeneous concept is, perhaps, a more general characterization of reactors than is involved in the other reactor projects of the power reactor program. Reactors may be defined as heterogeneous, meaning the core is composed of different materials separated one from the other, or homogeneous, signifying a uniform core material such as a solution or slurry. Thus the homogeneous reactor project is directed toward solving problems which will permit construction of reactors of a different engineering type than others being investigated on a project basis. There are many embodiments of the homogeneous principle. There are different degrees of technical feasibility within existing technology depending upon the particular design one is considering. The Commission's development program emphasizes aqueous systems but does include investigation of uranium and thorium systems, boiling and nonboiling operation, and single or two-region reactor designs. Major effort is directed toward a two-region thorium system believed to be capable of producing lower cost nuclear power than other designs which have fewer remaining development problems.

Primary responsibility for the homogeneous reactor project has been assigned to ORNL. This laboratory also designed, built, and operated the very successful HRE No. 1. The present program is focused on assembly of a second homogeneous reactor experiment (HRE No. 2). The concept of this reactor has been modified rather signifi-

cantly as the design progressed so that a much more useful reactor will be provided than originally planned. The reactor will be more powerful, with powers of 10 megawatts believed attainable at least intermittently compared with 3 megawatts in the original plans. It also will be more versatile and eventually will include a blanket system and chemical processing equipment. These modifications involve some additional costs but they now make it appear unnecessary to construct an intermediate scaled homogeneous power reactor since it is expected that the modified HRE No. 2 will provide most of the technology originally to be obtained from the intermediate-sized reactor.

Construction of the HRE No. 2, which is housed in the original HRE No. 1 building, was started in July. The HRE No. 1 was shut down and dismantled. Erection of the underground steel-lined reactor cell has been completed and installation of the "low pressure system" is in process. Contracts have been awarded and fabrication started on all major equipment, including the heat exchangers, core tank, pressure vessel, and circulating pumps. As a result of the increased scope of the HRE No. 2 project the scheduled startup date of the reactor is early 1956.

The development program for homogeneous reactors is composed of three main areas of study. These are component testing, a corrosion test program, and blanket and processing studies. Considerable mockup and component testing for HRE No. 2 has been conducted and development work on components suitable for larger scale reactors is underway. One of the principal problems associated with homogeneous reactors is the possible corrosion of the reactor core and primary piping system with the fuel and blanket materials. Extensive testing without radiation has indicated methods for maintaining adequately low corrosion rates on stainless steel, zirconium, and titanium. Recently an extensive program has been underway to evaluate the effect of reactor-induced radiation on the corrosion of materials of construction. This program includes examination and analysis of specimens of the dismantled HRE No. 1, and the testing of both static and circulating fuel solutions in operating reactors. Results from these experiments are still being evaluated.

It is planned that maximum use will be made of the HRE No. 2 in establishing this technology to a point at which larger scale homogeneous reactors may be constructed. It is hoped and believed that a larger scale homogenous reactor powerplant will be built in subsequent phases of the power demonstration reactor program. Various embodiments of the homogeneous reactor concept will continue under investigation as part of the Commission supported program, including studies and reactor experiments based on other homogeneous fuel and blanket systems. Designs and evaluations of homogeneous reactor designs for a wide range of power levels will be continued.

IV. OTHER REACTOR CONCEPTS

An essential part of the power reactor development program is the general research and development work. It is in this area that most new promising reactor concepts originate and are advanced to a state of technology which permits the planning of reactor construction. As a result of work during the past year two such concepts have

reached a point at which it is believed appropriate to plan additional experimental reactor projects.

Liquid metal fueled reactor

A reactor in which the fuel is carried in a liquid metal system has the potential advantages of simplified fuel processing such as in the aqueous homogeneous reactors plus high temperature at low pressure common to liquid metal cooled systems. One such reactor concept utilizing graphite as moderator and a uranium solution in bismuth as fuel has been carried to a reasonably advanced state of component development primarily by Brookhaven National Laboratory. Babcock & Wilcox is under contract to study the BNL data and calculations with a team of highly trained technical personnel on loan from several other organizations. Their objective is to determine technical feasibility and identify important areas for additional investigation. A final report on this study is expected about July 1955. Future plans for development of this technology will depend upon the results of this study and upon investigations of other fuel systems offering comparable advantages. The development of a nonaqueous fluid fuel system and reactor concept providing high temperatures, reasonable pressures, and simple processing schemes is considered an important area of advanced technology. The Commission will continue to support such development in a manner as justified by experimental results.

Organic moderated reactor experiment

Investigations of organic compounds as possible reactor moderator-coolants show several advantages for some of these materials. These advantages include low induced radioactivity, low corrosion of fuel elements, and high boiling point. Thus, they afford the possibility of reactors of the small size of water moderated units, operating at higher temperature with lower vessel pressure and practically no problems of corrosion. The major unknown in systems under investigation is the deposition characteristics of heat transfer surfaces under reactor conditions. Another problem is the rate of polymerization and decomposition of the organic moderator. Experiments now in progress are expected to clarify this uncertainty. It is believed that the next step in evaluation of this technology, assuming radiation-loop test results are satisfactory, should be a simple, inexpensive reactor experiment somewhat along the standards of the boiling water reactor experiments at the NRTS. This experiment would be designed to simulate conditions of heat flux, temperature, and coolant velocities contemplated for a practical power reactor of this type.

V. OTHER PROPOSED PROGRAM ACTION

In addition to the continued pursuit of the original experimental reactor projects and such other concepts as experimental results may justify pursuing on a project basis, certain other modifications or additions to the technical program are proposed in order to improve the probability of achieving economically competitive nuclear power on a wide front within a reasonable time and in order to improve the effectiveness of the program as a base for American assistance to other countries in the nuclear power field. These changes involve three

primary areas of activity: (*a*) reactor safety; (*b*) increased attention to designs in a wide range of power capacity; and (*c*) fuel technology.

Reactor safety

Reactor safety is of great importance in connection with civilian power reactors. A program has been established to investigate experimentally the behavior of various types of reactors under conditions of sudden large increases in reactivity. Such work should lead to fundamental knowledge of the mechanics of reactor transients. It will aid the assessment of reactor hazards and the design of reactors which are inherently safe. Extensive reactor safety studies appear to be a logical activity and responsibility of the Commission. It is intended that this activity eventually will include attention to research reactors and all of the power reactor concepts being explored on a project basis. Facilities will be provided for conducting these experiments and planning of specific tests will be undertaken by responsible development staff on the various reactor concepts, in cooperation with an operating staff for the facilities.

Small and intermediate sized nuclear powerplants

Present projects of the civilian power reactor program generally are focused on small experimental reactors (1,000 to 15,000 kilowatts, electrical) and on very large reference designs for central station plants (150,000 to 400,000 kilowatts, electrical) of each concept. The tendency toward large reference designs is the result of cost savings per unit of capacity which can be shown for large plants. Actually over 80 percent of the conventional powerplants built in the United States in 1953 were in the range from 25,000 to 150,000 kilowatts, electrical. An even larger percentage of powerplant requirements in other countries are in this size range and the lower powers are of particular interest to REA and public-power groups in this country. It is important that the potential role of these small and intermediate sized plants be evaluated more carefully. Most of this effort is planned as part of development and evaluation of the various concepts within the individual projects. The advantages of certain reactor types in specific power ranges will be more clearly defined. It is expected that much additional effort on design and evaluation of those smaller sized plants will be undertaken by groups outside the Commission-sponsored program.

Fuel systems

The fuel system is, of course, the most important part of nuclear powerplant planning. Nuclear power can be competitive only if the fuel system technology permits utilization of the enormous potential energy in fissionable materials at reasonable costs. The present Commission-sponsored program includes attention to the technology and economies of complete cycles in several fuel systems, involving both uranium and thorium. It is planned that this part of the program be expanded somewhat, particularly to take account of fuel requirements for reactors designed to operate on fuel slightly enriched in the average content of fissionable isotope in nuclear power systems which may not have the benefits of an isotope enrichment plant. It is important to recognize in connection with all development work on fuel systems that the most important phase of the work is investigation of behavior under irradiation. This includes; for example,

corrosion properties, and radiation stability. Such investigations require a large volume of testing in reactors and rate of progress depends largely upon availability of radiation test facilities.

VI. REVISED PROGRAM COST ESTIMATES

The program described in this statement is a program for providing a broad base of technology for a nuclear-power industry. It does not include Commission obligations which may be associated with assistance to other organizations in building and operating power demonstration reactors. Estimates of what these obligations may turn out to be are considered to be too indefinite and unreliable to warrant including them in this report. Thus, this is essentially a revised statement of the type of program described in the report of March 1954. The scope of the program has expanded and estimates of the total cost of the work have increased. The actual amount of increase will depend very much upon the scheduling of new experimental reactor projects and upon the scope of the reactor safety program. The estimated cost of completing the original reactor projects remains essentially unchanged although internal shifts among the projects appear warranted. However, additional projects and expansion of certain areas of development as described in this report may require as much as an additional $30 million during the period fiscal year 1956 through fiscal year 1958, exclusive of assistance to industrial groups on the power demonstration reactor program.

All research and development program plans naturally are conditioned upon any necessary congressional authorizations and appropriation of funds.

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